SEVEN-MONTH-OLDS' DISPLAY OF ANTICIPATORY HEART RATE DECELERATIONS IN AN S1+/S1- FIXED FORE-PERIOD PARADIGM

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1991

ACKNOWLEDGMENTS

Many people contributed to the successful completion of this dissertation. Kelli Salem and Fran Landis spent many hours "scoring" videotapes. Stacy Grossman, Michelle Krause and Kelli Salem all participated in the collection of the data. Their help was greatly appreciated. Finally, I would like to thank W. Keith Berg; his infinite patience and unflagging enthusiasm were instrumental in the preparation of this dissertation.

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August 1991

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Major Department: Psychology

This study assesses the ability of human infants to anticipate the arrival of temporally cued events as judged by changes in heart rate (HR) and looking responses in an S1+/S1- Fixed fore-period paradigm.

Sixteen 7-month-old infants participated in two separate sessions. During the training session the infants were exposed to 18 (paired) trials in which a 12 s 68 dB sine wave tone was paired with a 2 s presentation of an animated toy. The toy's activation began 6 s after the onset of this tone. During the test session the subjects were exposed to 10 more of these paired trials (S1+), and in addition, 10 non-paired trials (S1-) were randomly interspersed among the paired trials. The tones selected for paired and

non-paired conditions differed in pitch and pitch assignment was counter-balanced across subjects.

The test session HR data indicated that the infants responded with significant linear and quadratic trends over seconds in the paired condition ($F(1,15)=10.79$ and 11.80, respectively, both $p<.005$). The response to S1+ changed in form from quadratic in the first half of this session ($F(1,15)=8.67, p=.01$) to linear in the second half ($F(1,15)=9.04, p<.01$). No significant trends were found in the non-paired condition.

Analysis of the looking response indicated that during the first block of paired trials there was a significant linear increase in the probability of looking toward the S2 across the ISI ($F(1,13)=12.87$, $p<.005$). However, this response dropped out in the second half of the session. In contrast, on non-paired trials there were no significant trends during the first block of trials.

The HR response clearly demonstrates that the 7-month-olds were able to differentially use a cue to anticipate the arrival of the S2.

INTRODUCTION

Relevance of Anticipating

The ability to anticipate or forecast events which one will encounter is critically important to organizing behavior in a dynamic environment (Haith, in press). As Haith, Hazen and Goodman (1988) discuss, this ability is a ubiquitous phenomenon in adults, which is utilized over a broad range of temporal intervals and conceptual complexities. The development of this ability over the course of human infancy is poorly understood. This lack of understanding stems from the limited data bearing directly on anticipation as well as confusion about as to what constitutes this behavior.

This lack of knowledge undermines the integration of theories of adult cognitive development, which depend heavily on the concept of anticipation, with theories of infant cognitive development (Haith, in press). Thus, critical issues of continuity and discontinuity in development go unaddressed. The process of anticipation depends heavily on a knowledge of temporal information. Recently, Nelson (1986) has suggested a theory of infants' representation which is heavily dependent on temporal information. Nelson suggests that infants first understand the world through "generalized event representations." These representations are similar to scripts; they are a basic form of representations that provide temporal structure to an event and serve the function of predicting action and making plans.

Nelson reports that three-year-olds are sensitive to temporal structure and are able to report action sequences without error. More recent work with younger children (Bauer & Mandler, 1989; Bauer & Shore, 1987) have also demonstrated such temporal sensitivity. Bauer and Shore (1987) demonstrated that infants ranging from 17-23 months of age were better able to recall the components and order of causal events than arbitrary events (the difference between events being causal events have an inherent structure). Further evidence of the sensitivity of infants to the temporal structure of events is provided by Bauer and Mandler (1989), who demonstrated in two studies that infants as young as 20 months of age are more sensitive to the temporal structure in a causal sequence of events than to that in an arbitrary sequence.

In order for infants to follow the temporal order of a sequence of events they must at some level be associating one event with the next. The issues addressed in this dissertation deal with simpler situations but still address the nature of infants' abilities to temporally associate one stimulus with another. The literature I will review suggests that this process of association changes over the first year of infancy. A more comprehensive understanding of the development of associative learning in early infancy may well improve our understanding of more complicated event representations that develop later.

Although the terms expectation and anticipation appear often in discussions of infant cognitive development, these terms are often not explicitly defined nor precisely demonstrated. As a result, Berg and Donohue (in press) have defined these terms in an attempt to separate the related but distinct phenomena of association, expectation, and anticipation.

These authors describe anticipation as "a cognitive process that takes place <u>prior</u> to an event of interest or importance, and is focused upon it . . . Under optimal circumstances, anticipation will help the individual to process or enhance positive events, or will help them to mitigate or provide protection from negative ones." (Berg & Donohue, in press, p. 61) Anticipation is exclusively a pre-event process.

Although this description may seem obvious, it excluded many behaviors that have been characterized as indicating anticipation. All behavior that occurs after the event of interest is excluded by this definition. Berg and Donohue (in press) label those behaviors that occur after the fact (post event), but are indicative of knowledge about the stimulus pattern or event structure, as expectancy events. For example, the appearance of a P300 after the unexpected presentation of an "oddball" stimulus (Donchin & Coles, 1988) is identified as an expectancy effect. Although these types of responses indicate sensitivity to novel or unexpected stimuli, they are not direct measures of anticipation. Indeed, such expectancy responses can occur in the absence of any indication of anticipation. (i.e. Clifton, 1974a).

Evidence of expectancy effects in infancy is abundant. These effects have been demonstrated by researchers interested in social emotional development (Fagan & Ohr, 1985), the object concept (Ballargeon, in press) and motor responses (Starkey & Morant, 1986).

However, given the critical distinction between anticipation and expectancy effects, data on anticipation will be the focus of the subsequent review.

<u>The S1-S2 Paradigm.</u>

Berg and Donohue (in press) describe the fixed fore-period, S1-S2 paradigm, or the two-stimulus anticipation paradigm (e.g. Lang, Ohman & Simons, 1978) as follows: "(A) very general paradigm (that) consists of the presentation of a series of paired stimulus trials in which an initial cue stimulus is followed after a fixed interstimulus interval (ISI) by a second stimulus which is typically distinctive, important or imperative." (p.63)

A broad range of paradigms can be considered "members" of the S1-S2 paradigm (i.e. classical conditioning, fixed fore-period reaction time, temporal conditioning and long stimulus habituation studies) and can then be discussed using similar terminology. When responding is assessed during the ISI, pre-event responses, these various paradigms can provide information relevant to anticipation.

Evidence of Anticipation in Infants

Classical Conditioning

Rovee-Collier (1986) has recently argued that classical conditioning is the "process by which organisms acquire predictive information about the structure of their environment". (p.143) and is "a major means by which organisms initially adapt to and learn the structure of their environment" (p.153). These assertions are based on the interpretation that conditioned responses reflect a stimulus-stimulus expectation. Although I agree with this view, I would re-emphasize that classical conditioning studies that only measure post event information (e.g. on test or extinction trials) do not provide data that directly assess the ability to predict or anticipate.

There are numerous studies of classical conditioning in infancy in which responses such as eye blinks, limb withdrawal, crying, and sucking are measured. This substantial literature has been reviewed by Lipsitt (1963), Fitzgerald and Brackbill (1976), Sameroff and Cavanaugh (1979), and Rovee-Collier (1987), among others, and a complete review is not feasible or necessary here. However, a summary sufficient for present purposes is possible when illustrated with some relevant examples. In general, the results of studies of conditioning in newborns have been somewhat mixed; however, a sufficient number of well controlled studies have reported success. There is little doubt that by birth an association between stimuli can be formed. Among the various types of conditioning, appetitive and eyelid conditioning seem to be more successful than aversive conditioning (Rovee-Collier, 1987), though many studies of appetitive conditioning had questionable results because of failure to include appropriate control groups. Eyelid conditioning is successful, but requires a relatively short ISI (2.5 seconds, Little, Lipsitt & Rovee-Collier, 1984). Anticipatory eyeblink responses are reported under these conditions, but are often less robust then conditioned responding found during extinction or to CS-alone test trials (e.g., Little et al, 1984; Lipsitt, 1963). The reviewers cited above agree that the ease and generality of conditioning, particularly for anticipatory responses, increases within the first few months of life.

A study by Blass, Ganchow, and Steiner (1984) provides an possible exception to two of the generalizations noted above. In a well-controlled study they report anticipatory responses early in life and with long ISIs. These authors classically conditioned neonates by pairing stroking of the forehead as the CS with presentation of glucose, the US, using a 10 s ISI. One of two control groups provided information on sensitization effects that might occur during the ISI. During acquisition trials, both a "head-orient" movement and a "pucker-suck" activity developed during the ISI at substantially higher levels than the control group. Other studies have reported evidence of anticipatory classical conditioning, but this is the first to do so with such long ISIs when appropriate control conditions were employed. For our purposes, this report fails to provide information in one critically important area: the moment-by-moment changes in the response or information on response likelihood over the ISI. If we knew, for example, that responding developed close in time to the reinforcer, the results could more readily be interpreted as true anticipation rather than an activated or enhanced response to the CS. Nonetheless, the Blass et al. (1974) results provide encouraging if not unequivocal evidence that neonates have the capability to anticipate, even with the long ISI used in the heart rate studies.

Social/Emotional Studies

Several researchers have investigated the development of social expectations in infants (Lamb, 1981b; Lamb & Malkin, 1986; Gekoski, Rovee-Collier and Carulli-Rabinowitz, 1983). Lamb (1981b) reported that, although it is these expectations that are the bases of infants' complicated conceptions of social interactions, there was no good evidence of social expectations in the first 3 months of life . A study of anticipatory inhibition of crying to the arrival of a caretaker (Gekoski, Rovee-collier and Carulli-Rabinowitz,1983) suggests a marked increase in the behavior over the period of 4 to 6 months of age. This finding is supported by the finding of Lamb and Malkin (1986) who found that, anticipatory soothing based on social expectation becomes evident at 4 and 5 months of age.

Place Learning and Reaching Studies

Two other areas of study that have provided evidence of anticipatory responding are the research on place learning, generally carried out with older infants, and the studies of reaching, for which some research on very young infants exists. In studies of place learning (e.g., Acredolo, 1978; Acredolo & Evans, 1980; Mckenzie, Day and Ihsen, 1984), infants learn to anticipate an interesting event occurring to one side or the other by turning their head toward the expected site of the event. In Acredolo's work, infants 6, 9, and 11 months old learned to reliably orient their heads within fewer than 10 trials, with no significant difference among the age groups. In a more recent study, Mckenzie, Day and Ihsen (1984) found that 8-month-olds could reliably anticipate the location of an interesting event even when the infants were relocated several times.

Studies of infant reaching (e.g., Bowers, 1972; DiFranco, Muir, & Dodwell, 1978; von Hofsten, 1977) have demonstrated that older infants (and adults, as well) begin forming the hand and finger positions to conform to the shape and size of the object prior to the time the hand reaches the object. That is, there is an anticipation of the object prior to its actual retrieval. Other than Bowers (1972), the research generally finds this process developing between the second and third month of age at the earliest (DiFranco et al, 1978).

Pomerleau and Malcuit (1980) recorded heart rate while infants 1 to 6 months of age were being encouraged to reach. The initial heart rate pattern appeared to show the deceleration, acceleration, deceleration pattern seen in adults during the ISI of a two-stimulus paradigm. Interestingly, the accelerative component was greatest among the 5-6 month olds, those whom they found were most likely to reach when the toy was later brought near. The results point to the potential for combining the reaching paradigm and the recording of heart rate.

<u>Specific Studies of Anticipation in Infants: Non-HR</u>

In the last few years, Haith and his coworkers have presented a series of studies demonstrating most convincingly that infants 3 to 4 months of age can reliably and quickly learn to anticipate a sequence of visual events occurring at specific locations and times (e.g., Haith, Hazan, & Goodman, 1984; Canfield and Haith, 1991; McCarty, Haith & Robinson, 1988; McCarty & Haith, 1989). Typically, interesting slides are presented every 1.7 s either left or right of midline in an alternating sequence, or some other short, repetitive pattern. Anticipations are reported to occur 19 to 45 percent of the time, compared to about half that during periods of irregular sequences. They also report reliable reductions in reaction times for instances in which anticipations do not occur. Using a similar methodology, Canfield and Haith (1991) found that both 2 and 3-month-old infants were able to anticipate when a sequence alternated symmetrically from left to right. However, only the 3-month-olds were able to anticipate an asymmetrical sequence (L-L-R, L-L-L-R).

When longer intervals are employed, there is evidence that anticipation does not occur until somewhat later. Recently Ruff, Capozzoli, Dubiner, and Parrinello (1990) examined visual fixation time of infants from 5 to 11 months of age while they were awaiting the arrival of an interesting puppet during intervals that ranged from 5 to 25 s. They found that there was no age difference in the amount of time the infants spent looking toward the puppet stage as they waited, but that the 9- and 11-month-old infants concentrated their looking time later in the intervals between puppet events. As was noted, this temporal distribution of responses in older infants is what would be expected with the development of an anticipatory process. Comparing these results with those of Haith's suggests that the duration of the inter-event interval may be critical in determining the age at which anticipation can be observed.

Peg Hull Smith has carried out a series of studies of serial position learning in infants that bears some similarity to the work of Haith and co-workers described above, though Smith uses longer, 4 to 5 s ISIs (Smith, 1984; Smith, Arehart, Haaf & DeSaint Victor, 1989; Smith, Jankowski, Brewster, & Loboschefski, 1990). Smith's subjects are seated in front of a stimulus presentation apparatus which has apertures in each quadrant. These apertures may be operated to reveal visual stimuli. Five-month-old infants are initially presented with a sequential series of six or eight aperture openings selected from this possible array of four positions. The sequence either follows a rule-based, or randomly sequence. Subsequent to training with the sequence, the same series is presented repeatedly and the infants are tested for visual fixations which occur at the location of the next to-be-presented event in the sequence. The results are complex, and rates of anticipation are low, 20-60%, but Smith presents evidence that infants may be influenced by at least some of the simpler ordering rules. However, when the response measure was improved in the last article (Smith et al, 1990), the overall accuracy scores were not better for an ordered series than for a random series. As the authors note, the method may not have been optimal for generating anticipation. A larger set of training trials may enhance the rate of anticipation in this paradigm.

In a fascinating experiment, Benson and her colleagues (Benson, Arehart, Jennings, Boley and Kearns, 1989) reported that 9.5 and 11.5-month-old infants are able to demonstrate an expectation of the location of their mother by where they will crawl and how quickly. Infants received two baseline trials in which mother appeared with an enticing toy at fixed location in the room, and the infant was allowed to crawl to the location. On the third trial, the mother unexpectedly appeared 8 feet to the left or right of the baseline location. This three-trial sequence was repeated three times. All infants took less time to reach mother on the second of the baseline trials, and longer on the relocation trial, both results consistent with an expectation of location being quickly formed. Also, some of the infants (14% of the 11.5-month-olds, 7 percent of the 9.5-month-olds) actually began to make anticipatory corrections in their crawling on the later relocation trials before mother appeared at her new position.

Anticipatory HR Responses

Bohlin and Kjellberg (1979) reviewed adult heart rate (HR) studies which used the fixed fore-period S1-S2 paradigm and describe a triphasic HR response during the ISI. In its most complete form, this response develops after several stimulus pairings and consists of an initial deceleration (D1) followed by an acceleration (A) followed by a second deceleration (D2). The D1 component of the response appears to reflect an orienting response (OR) to the S1; however, it is ambiguous as to whether this is best characterized as a signal or nonsignal OR (Bohlin & Kjellberg 1979). The A component of the response has been hypothesized to reflect a variety of phenomena: information processing demands (Coles & Duncan-Johnson; 1975), significance of S1 (Walters & Porges; 1976), and response requirements at S2 (Chase, Graham & Graham; 1968). The D2, which tends to reach its nadir just prior to S2 onset, has been hypothesized to reflect anticipation of S2 by several investigators (e.g., Bohlin & Kjellberg, 1979; Coles & Duncan-Johnson, 1975;

Walters and Porges, 1976). Thus, for my purposes the D2 component is the most theoretically significant component for indication or assessment of anticipation.

As I have argued earlier (Donohue, 1989; Berg & Donohue, in press), HR is an excellent candidate for examining anticipatory processes in infants. The response measure has long been used to assess sensory and simple cognitive abilities in infants (see Von Bargen, 1983, for a review) and HR decelerations to stimulus change can be displayed as early as the neonatal period (see Berg & Berg, 1987, for a review).

Evidence of Developmental Changes in HR Patterns Using the S1-S2 Paradigm

The importance in distinguishing between anticipatory and expectancy effects is made evident when reviewing the limited infant literature examining heart rate responses in S1-S2 studies. Such reviews (Berg & Donohue in press; Donohue & Berg, 1991) found that evidence of anticipatory HR responses in neonates, though reported, is questionable at best.

For example, Crowell, Blurton, Kobayashi, McFarland, & Yang, (1976) reported successful conditioning in neonates, but the results are difficult to evaluate since they do not show the heart rate per se, but rather moment-by-moment t tests. There were also substantial changes in control groups indicative of sensitization effects. In other reports, Stamps and Porges (1975) and Stamps (1977) report anticipatory HR responses only in a sub-sample (post hoc) of the subjects when an analysis with inflated degrees of freedom were used. The division of subjects by gender and HR variability resulted in positive findings for females with high HR variability. However, the group sizes in the two studies were reduced to 5 subjects. The results are further called into question when Turco and Stamps (1980) tested two to seven-month-old infants and found anticipatory HR only in a small number of male subjects.

In contrast to the questionable anticipation results, Stamps and Porges (1975) and Stamps (1977) found clearer evidence of expectancy responses evident when the subjects responded to the omission of the S2 on S1 alone extinction trials. This pattern of findings, the lack of anticipatory HR responses and the presence of HR expectancy effects was first reported by Clifton (1974a). Clifton tested neonates in a classical conditioning paradigm in which a tone was paired with the presentation, by bottle, of a glucose solution. The neonates failed to evidence any HR indications of anticipation of the glucose solution. However, when the infants were presented with the first tone-only extinction trial, the newborns displayed significant HR decelerations at the end of the 6 s ISI, the point at which the bottle had previously been presented. Clifton referred to this as a "what happened" response to the absence of the S2. Clifton differentiated this post event "expectancy" effect from a "here it comes", or anticipatory response, typical of the adult (i.e., as indexed by the pre-event D2 heart rate response).

This lack of anticipation together with the presence of expectancy effects was also seen in two-month-olds tested by Davies and Berg (1983). These authors found HR decelerations to the absence of a stimulus change within a temporal conditioning paradigm. In contrast, seven-month-olds tested in the same study showed tentative evidence (non-significant) of an anticipatory HR deceleration to the up-coming stimulus change.

Tentative evidence of anticipatory HR decelerations was also seen in four-month-olds tested by Brooks and Berg (1979). This unexpected evidence resulted when the subjects were presented with 10 repetitions of a 20 s tone; the tone was sufficiently long that the onset could serve as an S1 to the offset (S2). A _post hoc_ analysis of the infants' heart rate using an ANOVA which included the period from 8 sec pre-offset to 4 s post-offset demonstrated a HR deceleration that increased with stimulus repetitions. However, only 70% of the subjects were responding in this manner.

The animal literature on conditioning of HR has also provided evidence of some developmental changes in anticipatory cardiac responding. For example, Bloch and Martinoya (1981) assessed HR during light/shock conditioning in kittens and found that prior to 21 days of age, the kittens showed no heart rate change in the ISI, even after 12 daily training sessions of 10 to 12 trials each. Kittens older than 21 days, however, showed evidence of an anticipatory deceleration developing during training. Soltysik, Wolfe, Garcia-Sanchez and Nicholas (1982) confirmed the presence of the anticipatory HR response in older kittens. Kittens 28 days old maintain a deceleratory response to the CS when it is paired with shock, but not when the CS is used in the unpaired control conditions. In further research with anticipatory HR change in kittens, Nicholas, Wolfe Soltysik, Garcia, Wilson and Abraham (1983) found anticipatory HR changes in 8 and 12-week-old cats when a puff of air was paired with a shock. However, this behavior was absent in the 1 and 4-week-old kittens.

Campbell and Ampuro (1985) found a similar developmental pattern in rats. After habituating a HR deceleration to a tone, the tone was then paired with a shock; 21 and 26-day-old subjects demonstrated anticipatory HR changes. In contrast, anticipatory responding was absent in the 16-day-olds tested.

The lack of ISI responding in the very young infant rats and kittens cannot be attributed to any general lack of the ability to generate cardiac responses early on, since there were clear responses in all kittens and rats both to the US, and to the CS in control groups and/or in pre-training baselines or habituation trials. Similarly the absence of an anticipatory response in human infants also cannot be attributable to the failure of the subjects to associate the S1 and S2, as expectancy effects were found in many of the studies testing young human infants. The animal literature, by contrast, often presents no data relevant to expectancy effects; thus the neonate animals may demonstrate this level of association as well. Based on this literature it would appear that at least for the heart rate response system, the young infants have a selective deficit in the anticipatory process; this deficit is often evident even when associations and expectancy effects are demonstrated.

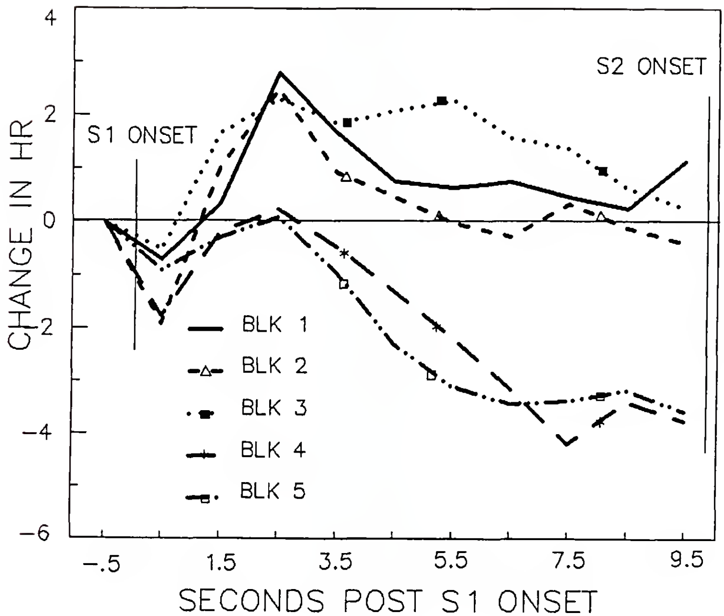
Seven-month-olds' anticipatory HR response in a simple S1-S2 Paradigm

The work of Brooks and Berg (1979) and of Davies and Berg (1983) showed suggestive evidence of a anticipatory HR decelerations. However, the studies were not really designed for the evaluation of anticipation, so the stimuli to be anticipated were relatively bland. In an attempt to provide clear evidence of anticipatory HR decelerations in infants, Donohue and Berg (1991) tested older (7-month-old) infants in the two-stimulus paradigm using a much more interesting S2, an animated, musical toy. Since this study is the basis for my dissertation research, it will be presented in some detail.

Sixteen 7-month-old infants were presented with trials comprised of a 15 s, 70 dB, controlled onset white noise (S1) and a 2 s midline presentation of an animated toy (S2) which began 10 seconds after noise onset. Since the noise remained on during the toy presentation and for an additional 3 seconds thereafter, effects of noise offset were separated from those due to toy onset. Infants received 20 trials, 17 of which were noise-toy paired trials, and three test trials on which the toy was omitted.

Change in HR during the 10 s ISI was analyzed (ANOVA including orthogonal trends) in 5 blocks of 4 trials each. No significant response trends were demonstrated over the first 3 trial blocks. But after 12 trials, a linear HR deceleration was evident (trial blocks 4 and 5, $F(1,15)=6.17$, $p<.05$, $F(1,15)=4.41$, $p=.05$, respectively) We believe these results to be the first unequivocal evidence of anticipatory heart rate responding in human infants (see figure 1).

On trials 6, 13 and 17, the S1 noise signal was presented as usual, but the toy presentation that usually followed was omitted. To evaluate possible responses to omission, heart rate was examined for one second prior to the omission and five seconds following it, and this activity was then compared to the corresponding interval on the preceding trial, in which



<u>Figure 1</u>: Donohue and Berg (1991) ISI data in blocks of 4 trials each. (copyright 1991 APA)

a toy was actually presented. The results indicate that there was no evidence of a response here until the third omission (trial 17), where a deceleration appeared which was very similar in amplitude and peak latency to the corresponding response to the actual toy presentation on the previous trial. The analysis of these data supported the appearance of the curves, with a significant Trial X Linear Seconds X Trial-type (paired vs. omission) interaction. This 3-way interaction was explained on follow-up analyses. For trials 5 and 6, and for trials 12 and 13, there were significant Trial-type X Seconds interactions, indicating the responses differed for paired and omission trials. But for trials 16 and 17, this interaction was not found, and the overall response was a significant deceleration.

Taken together, the heart rate results presented reflect two levels of association developing over trials. First, was the development by trial 17 of an ability to respond to the toy's absence at the end of the ISI. This response requires that an association has developed between the stimuli. Appearing as it did prior to the offset of the S1 it also requires that some temporal information about the S1-S2 relationship be known. Donohue and Berg (1991) argued that this response indicated the subjects were internally cued that a change in the normal stimulus pattern was detected. Using Berg's and Donohue's (in press) definitions given earlier, this response is characterized as an expectancy effect.

The second level of association, the ability to anticipate (and potentially prepare for) the arrival of the toy, was demonstrated in the response during the ISI. This response is characterized as anticipation within the Berg and Donohue (in press) framework, and is the first clear evidence of such a HR response in human infants.

Conspicuous by its absence is any of the traditional control conditions in the Donohue and Berg (1991) study. The absence of such a condition in the first demonstration of anticipatory HR in infants limits the confidence with which one can consider the results. The study described below was designed to replicate and extend the findings of Donohue and Berg (1991) by eliciting anticipatory HR change in an S1+/S1- fixed fore-period paradigm (analogous to differential conditioning). A positive result would serve as a replication of the general finding of

Donohue and Berg (1991), anticipatory HR changes in 7-month-olds. More importantly, it also would provide a within subject control condition through the use of a parallel to differential conditioning (S1+ and S1- trials). Furthermore, a positive result would demonstrate anticipation in a more complicated situation requiring the use of the differential cues.

METHODS

Subjects

The 7-month-old subjects were recruited by contacting the parents of age-appropriate infants born in Alachua County, FL, by letter and/or phone calls. The subjects were tested in two different sessions. Twenty-five subjects (M= 31 weeks; SD= 1.3) were included in the analysis of session 1. Nineteen additional subjects were tested but were eliminated due to inappropriate arousal state (18) or equipment failure (1). The subjects who successfully completed session 1 were invited back to participate in session 2. Sixteen subjects are included in the session 2 analysis. Nine additional subjects were tested but were eliminated due to inappropriate arousal state (8) or equipment failure (1).

Stimuli and Apparatus

Three stimuli were used in this study: two S1 stimuli and one S2 stimulus. S1 stimuli were controlled onset, 68 dB(A), 12 s sine waves, one at 794 Hz. and the other at 1454 Hz. These stimuli were generated by a Coulbourn S24-05 voltage controlled oscillator, gated through an Iconix electrical switch model 6837 (rise and fall time 100 ms), amplified by a Sansui AU-517 amplifier, and delivered through a KLH model six loud speaker. S2 was one of two animated percussive toys. During the S2 period, a toy was activated and illuminated within an enclosed box by Christmas tree lights. Tinted glass covered the opening of the box so that S2 was only visible when the enclosed Christmas tree lights were lit. The animated toy selected for presentation could be determined by a remote switch. The duration of both the S1 and S2 was timed automatically by an IBM PC using customized software.

We presented the parent holding the child with a pre-recorded masking stimulus played back through a Teac A-2300SX tape recorder, and delivered through Superex circumaural headphones. This stimulus consisted of a music background and randomly presented tones matching the S1s.

Cardiac data was collected using Sensor Medics Biopotential electrodes. The raw electrocardiogram (EKG) was amplified and filtered using a Beckman preamplifier (model 481b), amplifier, and coupler. A peak detector triggered by the R wave of each beat produced a pulse which was sent to a Tecmar Labmaster input/output board. This board, mounted in an IBM PC, was used to obtain on-line inter-beat interval timing.

Video tapes of the subjects were recorded using a Panasonic video camera and Curtis Mathes digital Hi Fi VHS recorder. This allowed for on-line monitoring of the subjects and later analysis of subject state and head position.

Procedure

Subjects for this study were tested in two sessions separated by 1 to 3 days. During both sessions the infant was seated on the lap of one of his/her parents in a sound attenuated experimental room. The subjects sat 1.5 m in front of the S2 presentation enclosure and the speaker located directly below it. This speaker, producing S1, faced the carpeted floor so that the sound was reflected broadly about the room.

Three electrodes were placed on the infant's chest to obtain HR data. The active leads were placed over the upper and lower portion of the sternum; the ground lead was placed over the lower left area of the rib cage. Placement of the active leads over the sternum reduced movement artifacts in the EKG signal. The inter-beat intervals were measured to the nearest millisecond by the custom IBM PC software. Subsequent to testing, the inter-beat intervals were converted into weighted average HR for each second of the trial for off-line statistical analysis.

Prior to testing, the parents were given no specific information regarding the temporal relationship between the stimuli, or the experimental hypothesis. The parent sitting with the infant was instructed to avoid movements and to interact with the infant as little as possible. The parent was then fitted with circumaural headphones that delivered the masking stimulus, the lights in the room were dimmed, and the experimental session began.

In session one, a training session, twenty trials were presented to each subject, 18 paired trials and two S2 omission trials. A paired trial (see figure 2) consisted of S1 which was 12 s in duration; at the sixth second after S1 onset, S2 commenced and had a duration of 2 s, resulting in 4 s of S1 alone after termination of S2. The omission trials were the same as the paired trials except S2 was omitted; these occurred on trials 8 and 20. Only one of the two S1 stimuli were used within subject in this initial session; however, the S1 stimuli employed in session 1

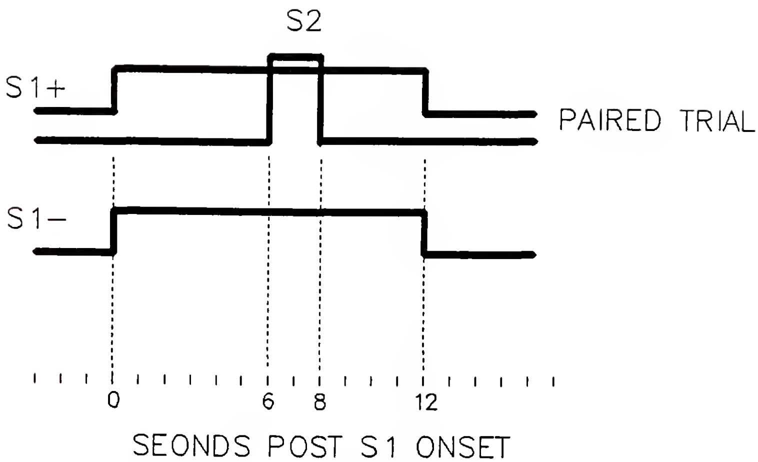


Figure 2: Sequence of stimulus presentation.

were counterbalanced across subjects. Following each 12 s trial, there was an interval varying from 7-12 s. At the end of this interval, the experimenter was able to initiate the next trial when the subject was in an alert state and facing S2. S1 onset occurred 3 sec after this trial initiation. Thus, the minimum inter-trial interval (S1 offset-S1 onset) was 10 s and the maximum varied but was typically no greater than 20 s.

After the first session, parents were given $5.00 to defray transportation and other expenses. Subjects who successfully completed the first experimental session were scheduled for a second session.

In session two, the S1 used in the first session was still paired with the toy, but unpaired trials using the different S1 were interspersed among the paired trials. The subjects were exposed to 10 more of the paired trials using the same S1 as in session 1 (now referred to as S1+). In addition, subjects received 10 randomly interspersed non-paired trials in which the S1 not used in session 1 (S1-), and differing from the S1+ in frequency, was presented (see figure 2). Tones used for S1+ and S1- were counterbalanced across subjects.

Following completion of the second experimental session, the experimental hypothesis was explained to the parents and they received $5.00.

Video tapes of the session were used to rate horizontal head position of the subjects in increments of 15 degrees for each .5 s of the trial. When the infant's head was positioned or within 15 degrees of S2, both horizontally and vertically, the subject was scored as "looking" toward S2.

Given both the relatively long interval between interesting S2 stimuli (approximate 20 s) and the number of trials involved, it was difficult for the infants to maintain an awake and alert state. An infant's entire data set was eliminated for reasons of inappropriate state if the parent requested that the session be ended for extended sleepiness or fussing, or if in the opinion of the experimenters one or the other of these conditions was true. Generally, a subject was eliminated when she would not stop seeking the attention of her parent and/or would struggle to escape a sitting position.

In addition, individual trials of subjects retained for analysis were replaced if during that trial two independent raters: a) rated the state of the infants as crying/fussy or drowsy/asleep, b) rated the infant as being distracted from the stimuli, or c) rated the parent as having interfered with the infant. This data would be replaced by that from the closest adjacent trial which was within the same trial block and of the same trial type. A subject's entire data set would be eliminated from analysis if the subject had more than four unusable trials in the session or had less than 50% usable heart rate data within every trial block (see below).

The two state raters maintained a reliability of 91.2% (agreements/total observations). Based on these ratings 95.2% of the session one data and 95.0% of the session two data were collected while the subjects were in an appropriate state and not distracted.

RESULTS

Both the HR and Looking results are based on trial blocks of 5 trials each. All the analyses performed were ANOVAs which included orthogonal trends over seconds, and trial blocks. All probability (*p*) values associated with repeated measures scores are corrected using a Greenhouse-Geiser procedure.

HR Responding

Session 1-Training

The response period was divided into two intervals for the second-by-second analyses. For all 20 trials, the 6 s inter-stimulus interval was evaluated to assess the anticipation of S2. On the two S2 omission trials (8, 20), the 5 second periods beginning when S2 was omitted were evaluated to assess the detection of the disruption of the S1-S2 relationship. For both intervals the sec-by-sec HR was measured as change from HR in the second prior to the interval of interest.

Anticipatory response

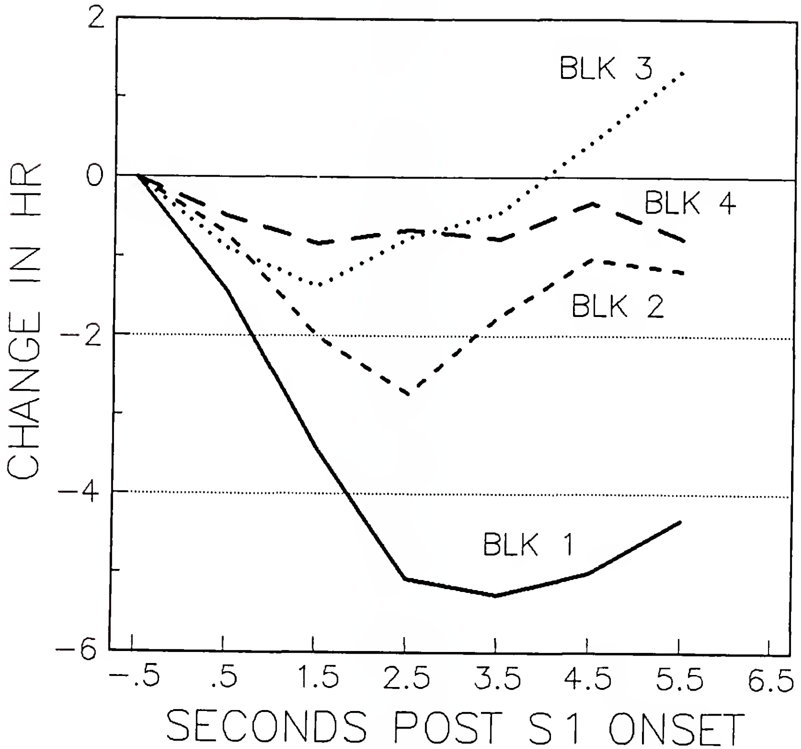
The HR response during the ISI habituated over the initial three trial blocks and then the deceleration appeared to increase somewhat on the last trial block (see figure 3); this resulted in a significant quadratic trial blocks by linear seconds interaction ($F(1,24)=8.67$, $p<.01$).

S2 omission response

On trial 8 the HR decelerated at the point in time the S2 should have appeared resulting in a significant linear deceleration ($\underline{F}(1,23)=4.73$, $\underline{p}<.05$). This effect was not found in trial 20 (see figure 4). The absence of the an omission response on trial 20 is not readily explained by a lack of interest in the S2 after 18 pairings. The response to S2 on the last paired trial, trial 19, is comparable to the response to S2 on the first block of trials (see figure 5). Further evidence against that hypothesis is revealed when the response to S2 across trial blocks is examined; the response to S2 over trial blocks does not appear to demonstrate habituation (see figure 6).

Session 2-Test

The 10 trials in each condition (S1+/S1- trials) were grouped into blocks of 5 trials each and results were assessed with a conditions (2) by trial blocks (2) by seconds ANOVA. Anticipatory HR change was assessed over the same interval as in session 1.



<u>Figure 3</u>: Session 1 ISI HR response, in blocks of 5 trials.

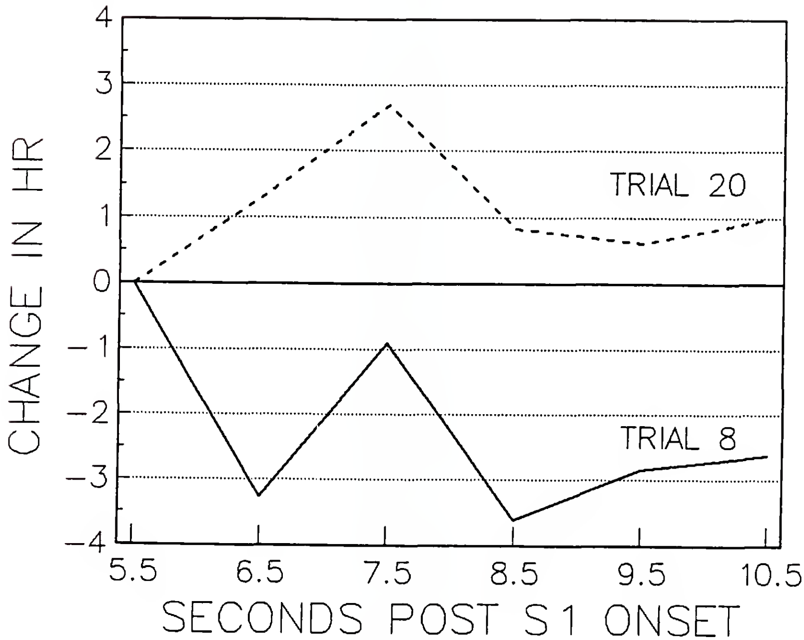


Figure 4: Session 1 post S2 omission response.

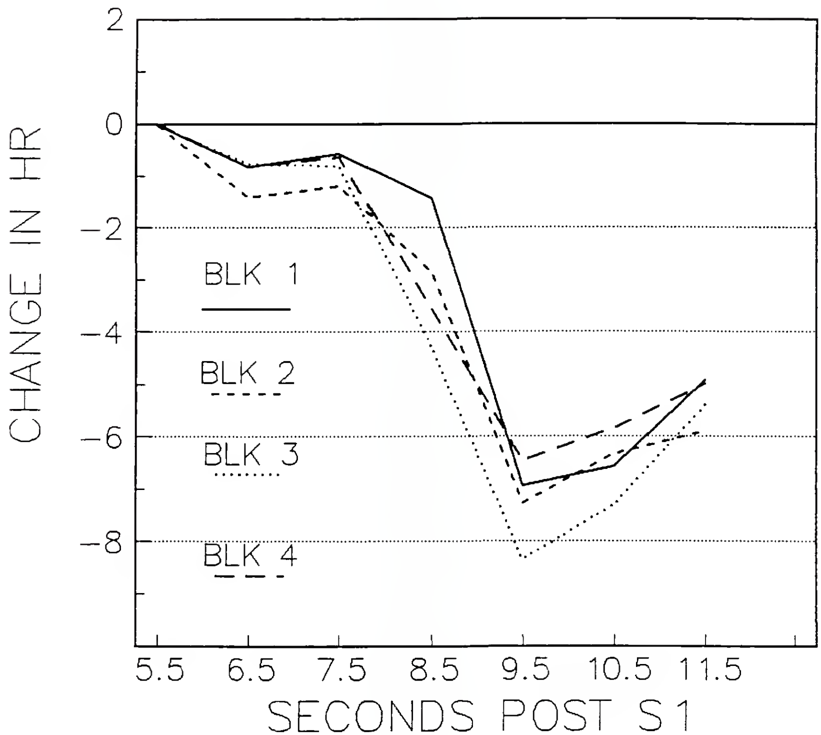
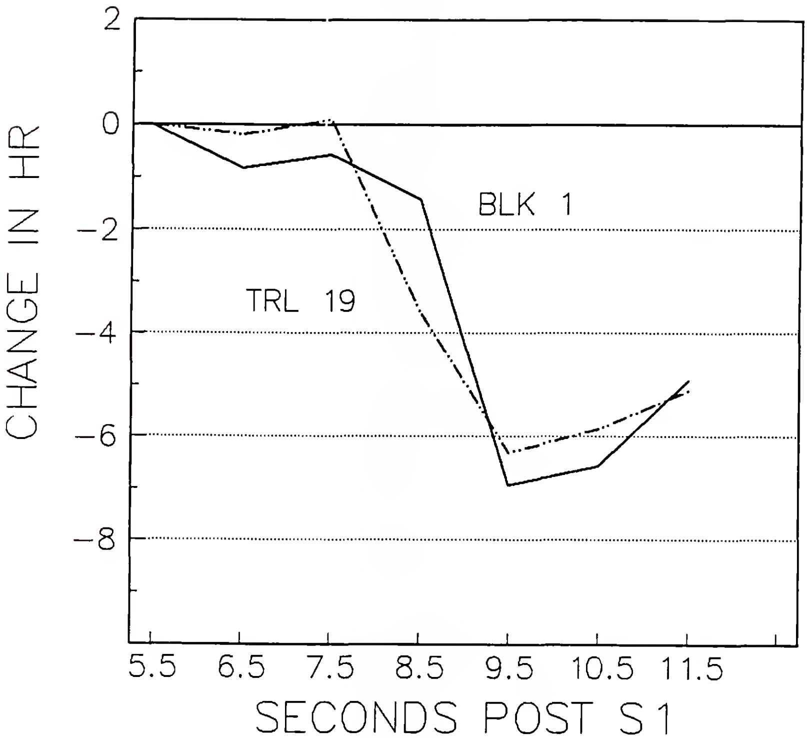


Figure 5: Session 1 response to S2, in blocks of 5 trials



<u>Figure 6</u>: Session 1 response to S2, block 1 and trial 19.

The HR response during the ISI was examined to assess the presence of differential conditioning on the part of the infants. Decelerative responses appeared to be present on both trial blocks of both S1 types, but were larger in response to S1+ than S1- (see figure 7). This was reflected by the Condition by quadratic Second interaction, $\underline{F}(1,15)=5.15, \underline{p}<.05$. Follow up analysis of each condition separately revealed a significant linear as well as quadratic trends across Seconds in the S1+ condition, $\underline{F}s(1,15)=10.79$ and 11.80, respectively, both $\underline{p}<.005$. However, no significant effects over seconds were seen in the S1- condition.

Although these effects support an interpretation of differential anticipatory responding, my a priori hypothesis regarding change over the session indicated the value in analyzing each of the four blocks separately (see figure 8). Analysis of the S1- condition revealed no significant trends in either block. In contrast, the first block of the S1+ condition contained a significant quadratic trend across seconds ($\underline{F}(1,15)=8.67, \underline{p}=.01$) and block two contained a significant linear seconds trend ($\underline{F}(1,15)=9.04, \underline{p}<.01$). Thus, the changes in response

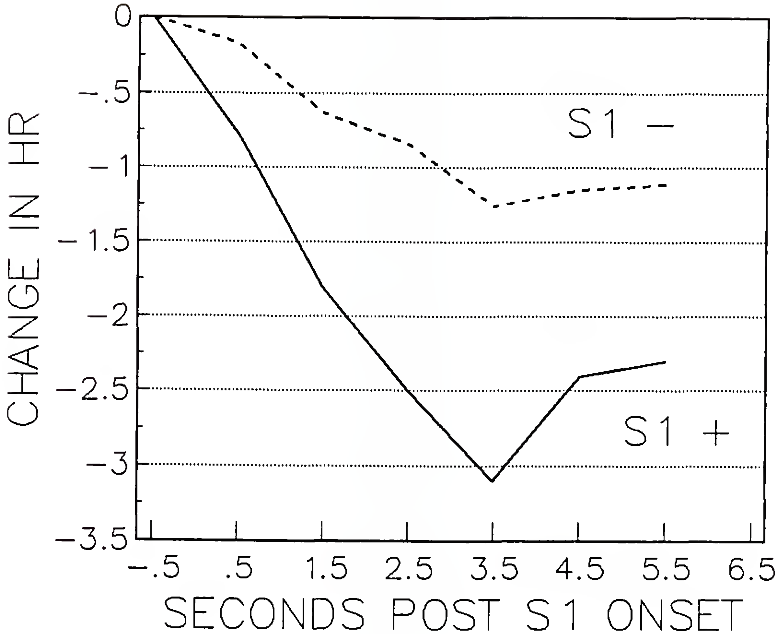
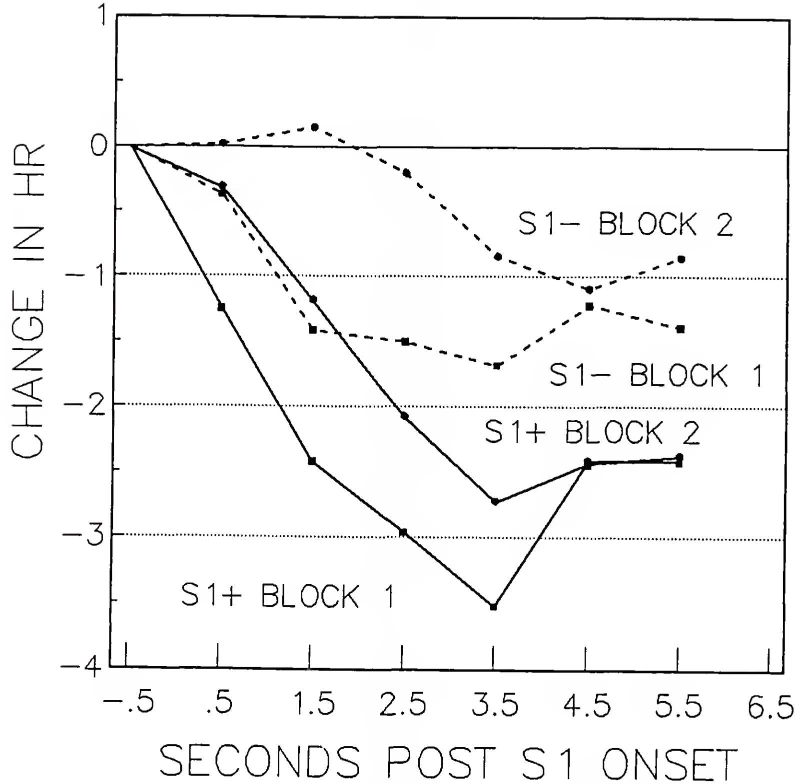


Figure 7: Session 2 ISI HR response, by condition.



<u>Figure 8</u>: Session 2 ISI HR response, by condition by block.

form across the blocks seemed to principally derive from the S1+ conditions. The change to the linear response form for the stimulus condition is indicative most specifically of the anticipatory, D2 type of response.

Looking Response

Session 1-Training

Anticipatory response

The data from the initial sixteen subjects were analyzed; they revealed no significant results, nor trends towards results consistent with anticipatory responses. Given the time-consuming nature of this data reduction and analysis, and the absence of any significant looking findings in a previous simple conditioning study (Donohue & Berg, 1991), analysis of the remaining subjects tested in session 1 was suspended.

Omission response

The looking data revealed no evidence of response to the omitted S2 on either trial 8 or 20.

Session 2-Test

Due to equipment failure, only 14 of the 16 subjects who provided data for session 1 are included in this analysis.

In the overall analysis there were both significant linear and quadratic trends over seconds ($F(1, 13)=6.17$, $p<.05$; $F(1, 13) = 6.28$, $p<.05$, respectively), (See figure 9). Although there were no significant interactions by condition, the <u>a priori</u> hypothesis, as well as the results of the HR analyses, suggested separate analyses for both S1+ and S1- conditions be made.

In the S1+ condition, the data appeared to be in a linear configuration because the probability that the subject would be looking at the position of S2 rose during the ISI (from 30 % looking at 0 s to 45% looking at 6 s). In the S1+ condition, there was an overall linear trend over seconds ($\underline{F}(1,13) = 5.97$, $\underline{p}<.05$). However, it is qualified by a significant block by linear second interaction ($\underline{F}(1, 13) = 5.25$, $\underline{p}<.05$). Block 1 demonstrated a significant linear trend ($\underline{F}(1, 13) = 12.87$, $\underline{p}<.005$), while Block 2 exhibited no significant trends (see figure 10).

In the S1- condition, the highest probability of looking was during the middle of the ISI, with lower probabilities at the beginning and end. (See figure 9) This pattern resulted in a significant quadratic trend

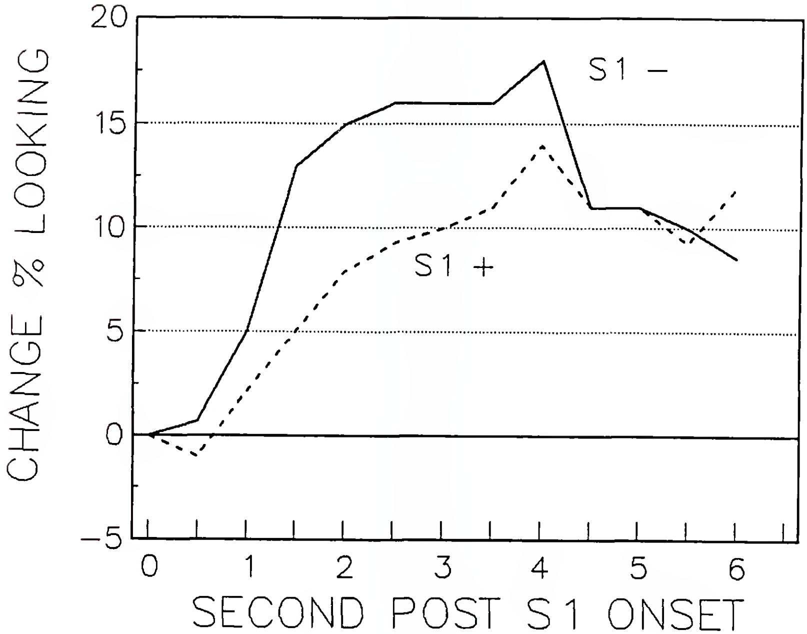
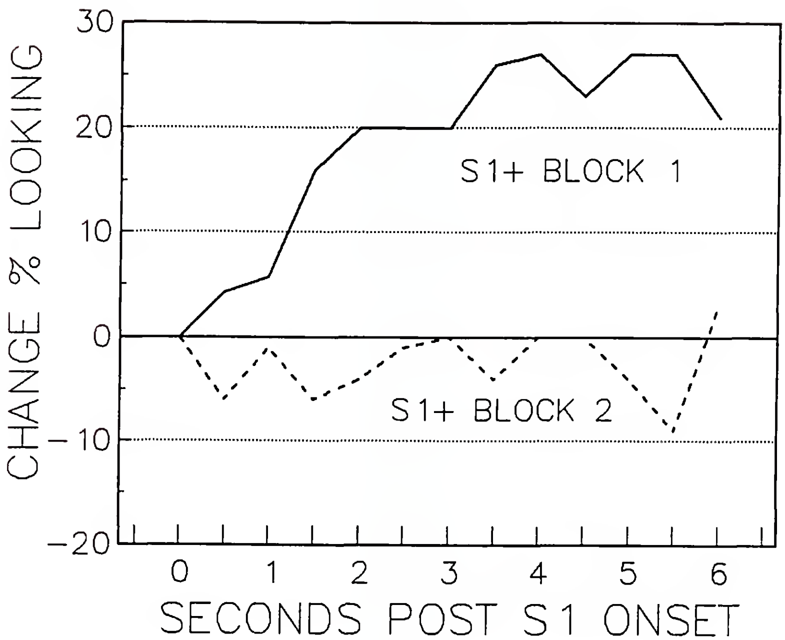


Figure 9: Session 2 ISI looking response, by condition.



<u>Figure 10</u>: Session 2 ISI looking response, S1+ condition by block.

over seconds ($F(1, 13) = 7.94$, $p < .05$). There were no significant interactions in the S1- condition, but to provide parallel information to the S1+ condition, each block was analyzed separately. Block 1 showed no significant trends, but Block 2 exhibited a significant quadratic trend over seconds effect ($F(1, 13) = 7.29$, $p<.05$).

DISCUSSION

These data present the first evidence of differential anticipatory HR responding in the human infant. They replicate the finding of Donohue and Berg (1991), which first demonstrated clear anticipatory HR responding in 7-month-olds, and expand the circumstances under which anticipatory responses have been demonstrated.

The HR response in session one provides only equivocal evidence for the development of both anticipatory and expectancy responses. The change in ISI response curves might appear to result from simple habituation. However, the predicted significant quadratic trial block by linear second interaction is not the trend expected to occur with simple habituation. This change over trial blocks may reflect the habituation of responses to the S1 followed by the beginning of a shift toward anticipatory responding to S2.

These effects, occurring during the ISI, are less compelling than those seen in the earlier study of simple conditioning in 7-month-olds (Donohue & Berg, 1991). Several differences in session 1 and the earlier study may account for the reduced evidence of anticipation. One difference between the studies is that a 6 s ISI was used here compared to the 10 s ISI used by Donohue and Berg. An additional difference is that different S1s were employed. Donohue and Berg used a white noise S1 which caused HR accelerations in half the subjects; the tones used here resulted in larger and more consistent decelerations. This larger deceleration to S1 together with a shorter ISI may have interfered with the clear display of a late component (anticipatory) response. Given these differences it is particularly inappropriate to accept the null hypothesis here; the interference with the HR output system is not equivalent to the absence of anticipation. In any case, the possible importance of the ISI duration and S1 difference can and should be directly tested in future studies.

The display of an omission response in trial 8 but not in trial 19 during session 1 was unexpected. Although the display of an omission response in infants after only 8 pairings is consistent with the findings of both Brooks and Berg (1979) and Davies and Berg (1983), the study most similar to the present one, Donohue and Berg (1991), failed to find evidence of omission responses before trial 13. Donohue and Berg hypothesized the delay in omission responding to be the result of the more complicated nature of the trials used in their study. As in the present study, the S2 onset and offset of the Donohue and Berg study occurred in the midst of an ongoing S1. Given the similar nature of the trials and stimuli used in the two studies, I expected a late display of an omission to reoccur. The unexpected significant omission response on trial 8 may be attributable to the shorter ISI used here. This shorter interval may facilitate the timing of the S1-S2 interval and lead to the display of an expectancy effect earlier in the experimental session. Perhaps more difficult to explain is the absence of a significant response to S2 omission on trial 19. It is not readily explained by a lack of interest in the S2 late in the session as there was little decline in the HR response to its presence. Neither is it readily explained by the shorter ISI used here. Given the unexpected pattern of the omission response displayed here, this result should be interpreted cautiously. Thus, both anticipatory and expectancy responses during the training session are equivocal. However, the responses during this training session are, obviously, not the primary focus of this study nor do they directly bear on the interpretation of the results from the test session.

In contrast to the HR responses in session one, the anticipatory HR response in session two is both significant and fits _a priori_ hypotheses. The HR response following the S1+ was larger than that following the S1-. This result is opposite to that predicted by a habituation hypothesis. Habituation could lead to differential responding to S1, in that the infants had been exposed to the S1+ but not the S1- during the preceding session. The significant linear response following S1+ in the second block when contrasted to the lack of a significant response to the S1- in that block is particularly compelling and suggests a clear development of an anticipatory HR deceleration. Although there is no D1-A-D2 response pattern displayed during the ISI, the continued presence of this deceleration after S1+ is consistent with anticipatory responding in short ISI studies of adults (Bohlin & Kjeilberg, 1979). These authors reported that the shortening of the ISI tends to truncate the D1 and A components of the ISI response. Although a 6 s ISI is sufficient for displaying the 3 component anticipatory HR response in adults (e.g., Lang et al., 1978), the present data when compared to that of Donohue and Berg (1991) suggests that longer ISIs should be used with infants.

The HR results from session two generally satisfy the definition of anticipation provided in the introduction of this paper. The presence of a larger response to S1+ than S1- in the test session satisfies the temporal requirement of responding before S2, and indicates that the subjects are responding to the S1s in a differential manner. These responses demonstrate that S1+ has become a more salient (or signal) stimulus to the subjects. However, this response pattern could be attributed to a general sensitization to S1+ rather than the more restrictive interpretation as reflecting anticipation of the S2. The critical question is whether the response has become focused on S2 or simply is enhanced responding to S1+. A shift in the HR deceleration toward the later part of the ISI is needed to convincingly demonstrate the focus on S2. Although the HR change following S1+ is consistently larger than that following S1-, the change to a linear response following S1+ in block two is particularly fitting with the shift in focus to S2. This shift in deceleration to later in the ISI suggests anticipation rather than simple S1+ response enhancement. This response pattern in short ISI studies has been identified as indicating anticipation of S2 (Bohlin & Kjeilberg, 1979). The shift of the peak HR deceleration to late in the interval fits the requirement of the definition that the response enhance the intake of interesting stimuli, as HR deceleration has been identified with the enhanced processing of external stimuli (Graham & Clifton, 1966; Lacey & Lacey 1974).

A possible alternative explanation for the change in the ISI responses would be simply that habituation across blocks had occurred. There is some support for this interpretation as the quadratic aspect of the overall response decreased across blocks (Block by quadratic Seconds ($F(1,15)=6.06$, $p<.05$)). However, while the quadratic effect decreased, the linear component of the S1+ response increased over blocks. This was evident from the shift from the quadratic to linear trends in the S1+ condition and the absence of any significant trends in block 2 of the S1- condition. These changes precisely match my a priori predictions. Additionally, the maintenance of a similar deceleration late in the ISI across S1+ blocks is difficult to reconcile with an interpretation that relies solely on habituation. The data seem to suggest two processes are occurring simultaneously: a decrease over blocks in the earlier deceleratory component, reaction to S1 onset, and the increase in the later deceleratory component, the anticipation of S2.

The looking response data are less compelling. As with Donohue and Berg (1991), there is no support for concluding that the infants are either visually anticipating the appearance of S2 or detecting its omission during a simple S1-S2 paradigm (session one). During the differential session, some of the looking data suggests that the infants may selectively anticipate the arrival of S2; however, this effect is only present during the first half of the session. Although differential looking is only seen in block one, it should be noted that the HR response is already exhibiting differences across conditions in this block. But, given the absence of evidence of anticipatory looking in block two, I feel these results should be interpreted with caution.

It should also be noted that the paradigm used here was not imperative. The infants response was, to use Haith's (in press) term, gratuitous; that is, it had no effect on the environment. Further, both the S1 and S2 were presented directly in front of the infant, where they would typically be looking. Therefore, this paradigm may be less potent for eliciting anticipatory head turns than an instrumental paradigm.

The absence of a clear convergence of the HR and looking measure may to some readers undermine the importance of the HR indications of anticipation. This would be a mistake. First, as Haith (1990) cogently asserts, the discussion of infant abilities in a dichotomous (can/can't do it) manner is incorrect and simple minded. Haith suggests that the role of the infancy researcher is to describe the changing manifestation of the infant's abilities; therefore, infant abilities need to be discussed in terms of at what age, under what circumstances and in what manner infants are able to display their abilities. At this age, under these circumstances, the infants more clearly display anticipation in their HR responding. Other circumstances, such as those employed by Haith et. al. (1988) may favor visual-motor indices of anticipation, possibly in the absence of anticipatory HR responses. Sananes, Gaddy and Campbell (1988) note such a situation. In the infantile rat, somatomotor conditioned responding predates, developmentally, the display of conditioned HR responses.

In this circumstance, few would argue that the absence of the HR indices of conditioning diminishes the value of the somatomotor response. I see no reason to do the reverse here. Rather, the question of interest is, under what circumstances various anticipatory measures converge and diverge. The HR response is of particular interest here in that it has been extensively studied in humans across ontogeny and under a variety of cognitive demands; therefore, when making developmental comparisons, this measure may have special appeal.

The HR studies of early infants in which expectancy effects, but not anticipatory effects, were found when compared to the HR studies of older subjects in which anticipatory responses are found, suggest that the same change may be occurring in other measures of anticipatory responding. Such changes would have implications in a variety of content areas. Anticipation rather than expectancy effects are unequivocally future-oriented behavior. Expectancy effects in and of themselves may simply reflect a violation of a memory trace, that is, not recognized until after the fact. In this case, expectancy effects do not directly bear on the issue of planning and preparing. Thus, they do not directly bear on the infants exercising control over their environment. The difference between preparing for and simply reacting to the stimuli one encounters is clearly worth distinguishing.

Differentiating the specific nature of the infants' temporal understanding of the world is particularly important given the hypothesized importance of this type of cognitive ability. Lamb (1981) hypothesis that expectancies are the bases of trust and social relations (which may be the most important accomplishment in infancy). This suggests that a differentiation of expectancy and anticipation may be critical in understanding the changing nature of infant social interactions.

Nelson's (1986) concept of generalized event representations are critically dependant on the understanding of temporal relations within events. The work of Bauer and Mandler (Bauer & Mandler, 1989; Bauer & Shore, 1987) suggests that infants are sensitive to this information. However, this information may be either understood from the view of an anticipatory or expectancy perspective. Consideration of this distinction may well serve to further enhance our understanding of the type of representation Nelson proposes.

The central nature of concepts of anticipation and goal-oriented behavior to theories of adult cognition (Haith, In press), suggests that the most broad implication of expanding information on anticipation in infants may be to unify theorizing on the nature of cognition of adults and infants.

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August 1991

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